

## **Smagglce: SURFACE MODELING AND GRID GENERATION FOR ICED AIRFOILS, PHASE 1 RESULTS**

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### **Abstract**

Smagglce (Surface Modeling and Grid Generation for Iced Airfoils) is a software toolkit used in the process of aerodynamic performance prediction of iced airfoils with grid-based Computational Fluid Dynamics (CFD). It includes tools for data probing, boundary smoothing, domain decomposition, and structured grid generation and refinement. Smagglce provides the underlying computations to perform these functions, a GUI (Graphical User Interface) to control and interact with those functions, and graphical displays of results. It is being developed at NASA Glenn Research Center.

This paper discusses the overall design of Smagglce as well as what has been implemented in Phase 1. Phase 1 results provide two types of software tools: interactive ice shape probing and interactive ice shape control. The ice shape probing tools will provide aircraft icing engineers and scientists with an interactive means to measure the physical characteristics of ice shapes. On the other hand, the ice shape control features of Smagglce will allow engineers to examine input geometry data, correct or modify any deficiencies in the geometry, and perform controlled systematic smoothing to a level that will make the CFD process manageable.

### **Introduction**

Airfoil performance degradation due to ice can be measured from aerodynamic tunnel testing. Two-dimensional iced airfoil performance can also be predicted by numerical simulation using CFD. The use of CFD tools has demonstrated its potential as an efficient low-cost means of predicting post-ice accretion aerodynamic performance<sup>[1]</sup>. Ice accretion itself may be obtained from either icing research tunnels, actual flights, or an ice accretion prediction code such as LEWICE<sup>[2]</sup>. Figure 1 shows the process of deter-

mining iced airfoil performance from the iced airfoil geometry. Smagglce will support this process by providing tools for measuring ice shape characteristics, preparing the ice surface for gridding, defining and modifying the flow domain, and generating the grid.

Trying to apply existing CFD tools to aircraft icing problems with their characteristic highly irregular ice shapes, which may include sharp corners and/or very high curvature segments, has been a very difficult and labor-intensive task for CFD engineers. The study done in reference 1 indicates that semi-automatic software can improve the efficiency of this process, thereby improving the usefulness of icing CFD. Existing structured grid generation tools could be either inadequate or very inefficient when applied to the rough textured ice shapes found on iced airfoils. Smagglce, however, is specifically designed for iced airfoils. It has special algorithms for parametric mapping, smoothing, refinement, and explicit local and global grid control to help create the quality grids that are required for complicated ice shapes. Smagglce performs systematic smoothing of ice shape data using control points<sup>[1]</sup>. It will generate field grids using a control point formulation<sup>[3]</sup> in a rectangular computational domain using a parametric mapping technique<sup>[4]</sup>. Effectiveness of these technologies were tested and demonstrated in an earlier study<sup>[5]</sup>.

Most iced aircraft wing problems are three-dimensional problems. However, full 3D CFD processing from 3D geometry (i.e., 3D ice surface scanning/definition), to grid generation, to flow simulation will remain very difficult and computationally expensive in the foreseeable future. Thus, Smagglce is being developed for 2D interactive icing CFD, which will complement wind tunnel testing and/or flight experiments.

Smagglce will generate multi-block structured grids, rather than other grid topologies such as unstructured, Cartesian, overset, or hybrid. If the grid generation

aspect of CFD was the only concern, then grid technologies other than structured could have been selected for the code. However, the value of any component technology must be weighed in terms of its contribution to the entire process, which includes surface modeling, grid generation, and Navier-Stokes simulation. At present, Navier-Stokes CFD is more efficient, mature, and reliable on structured grids than on other types of grids. Hence, structured grids will provide greater overall benefit in terms of accuracy and efficiency with the semi-automated geometry modeling and grid generation process of SmagglIce.

SmagglIce is semi-automatic, i.e., some of its functions are highly interactive, some require user input of parameters, and some are fully automatic. Although fully automatic processing is ultimately desired for all functions, the combined interactive-automatic approach will utilize human intelligence as well as the rapidly advancing computational/graphical capability of computers. Icing CFD needs the best attributes of both.

SmagglIce is being developed in planned phases in order to make it available to the aircraft icing community at the end of each phase, with the opportunity for feedback at each phase. Development in Phase 1 involved providing two types of software tools: interactive ice shape probing and interactive ice shape control in preparation for gridding. Development in Phase 2 will provide for domain decomposition and gridding, with tools appropriate for iced airfoils. Phase 3 will tie SmagglIce with the flow solver WIND<sup>[6]</sup>, allowing for control and feedback between the two.

## Phase 1 Details

### Ice Shape Probing

Interactive ice shape probing is used in the process of characterizing ice shapes. Probing involves making measurements of the data on the screen, recording those measurements in a table, and saving them to a file. Figure 2 shows the controls used during probing operations and examples of measurements.

Once the boundary data is read in, the user may make probing measurements. These include: point location (e.g., ice limits), distance between two points (e.g., ice horn height or width), arc length (i.e., the distance along the boundary between two points on that boundary), angle between two lines (e.g., horn angle), and X/C ((x-xLeadingEdge)/chordLength). Location and distance may be normalized by the chord length of a clean airfoil. The probe points can be selected by various methods: the closest point to any object, the closest point to the current object, the closest point to the reference object, or an arbitrary point in space. Probing information may be saved to a text file and a

corresponding graphics display can be saved in the following image format: GIF, TIFF, and PPM.

### Ice Shape Control

Interactive ice shape control is used to prepare the surface for gridding. The types of functions that can be applied to surfaces are curve smoothing, discretization, and reshaping. Any subcurve (or the entire curve) of an element can be selected for processing. Systematic smoothing of the iced boundaries in a controlled manner is accomplished using the control point formulation described in reference 3 and illustrated in references 1 and 5. Users can control the level of smoothing by choosing the number of control points in constructing curves. Curve discretization provides a means of increasing/decreasing the number of points, distributing the points by curvature, and controlling the uniformity of their distribution. In addition, hyperbolic tangent stretching is provided. Direct reshaping of the curve (to perhaps correct obvious ice shape errors) is done by dragging control points associated with the curve. These control features of SmagglIce not only prepare the ice surface for the grid-based CFD, but they also allow users to correct any deficiencies (e.g., tangles, gaps, too many or too few points) in the input data. Figure 3 shows the controls used when modifying the curve using free form control.

## Graphical User Interface

The SmagglIce GUI provides an easy and intuitive interface for the user to interact with the data. Because SmagglIce is highly interactive, this user interface plays a critical role.

The SmagglIce GUI consists of a primary Main Window titled "SmagglIce" and other sub-windows. The SmagglIce Main Window (Figure 4) includes the following distinctive areas: **Menu Bar**, **Graphics Drawing Area**, **View Manipulations**, **Information**, **Current Object Info**, and **Graphics Window Mode**. In order to present a consistent user interface, the GUI was designed to support current features as well as ones that will be implemented in future phases.

The **Menu Bar** organizes the features of the application. There are nine menu items in the Menu Bar: *File*, *Edit*, *View*, *Probe*, *Boundary*, *Grid-CN*, *Grid-Direct*, *Solution*, and *Help*. The *File* menu contains components for performing actions on files, such as reading data, saving data, and saving an image of the screen. The *Edit* menu is used for performing actions on the current data of the application (such as "Clear All,."). The *View* Menu contains components for changing the user's view of the data. The *Probe* menu allows the user to measure ice shape characteristics,

designate an object to be the reference airfoil, highlight the reference airfoil, and display probing markers. The *Boundary* menu allows subcurve selection and modification, including discretizing and smoothing boundaries of objects. The *Grid-CN* and *Grid-Direct* menus will allow the user to perform grid generation and modification. The *Solution* menu will allow the user to read in and display solution data that is associated with a grid. The *Help* menu allows the user to access documentation and hint information.

The **Graphics Drawing Area** is where geometry is displayed and direct interactive manipulation of the geometry is performed.

The **View Manipulation** area contains six icon push-buttons and the arrow icons, which modify the view of the geometry without changing the data itself. The first set of buttons (*Translate*, *Scale*, and *Area Zoom*) set active mouse modes so that mouse button presses and movements modify the view continuously. The second set of buttons (*Full View*, *Zoom In*, and *Zoom Out*) and the arrow buttons labeled *Translate* change the view immediately when you press one of them.

The **Information** area is in the left-hand side of the Main Window. While the user interacts with the graphics window, relevant information is displayed in this scrollable text area. For example, while probing, the coordinates of points are displayed here before being recorded. As another example, when a subcurve is being selected, information about the subcurve end-points and the number of points in the subcurve is displayed here.

Because there may be multiple objects, there is a concept of a current object, to which functions may be applied. SmagglIce provides a mechanism to switch to another object, setting that as the current object. The **Current Object Info** area displays information about the current object such as: the type of object, its index number, the number of points, and a diagram indicating the object type.

The **Graphics Window Mode** displays the current mode along with instructions. Depending on the mode, mouse movements and button clicks will have different effects.

## **Implementation Issues**

SmagglIce is written in FORTRAN and C. FORTRAN is used for the computational routines; C is used for the GUI, control, interaction, graphics, and memory management. It is intended to run on any UNIX platform and has been tested on SGI, Sun, IBM RS6000, and HP systems. The GUI was developed for X-windows, using Motif, Xt Intrinsics, and Xlib func-

tions. This will aid in the portability of the user interface across multiple computer platforms running X. OpenGL is used for the graphics drawing. It uses the GLX extensions to X to interface with the windowing system, but the Mesa library<sup>[7]</sup> can be used if the workstation does not have OpenGL or if the X server does not support the GLX extensions.

Dynamic memory management is used to allocate only as much memory as is necessary for data storage and access. This allows the same executable to process smaller models on machines with less memory, and larger models on machines with more memory. It also allows multiple input files to be read in and processed during a single session. In addition, when data is no longer needed during a session, it can be cleared to allow for reading in new data. Figure 5 shows the data structures that make use of dynamic memory in Phase 1 of SmagglIce. As objects are read in, memory is allocated for them to store the object type as well as attributes describing the object. Space is also allocated for the data points defining the geometry, and a pointer stored with the object. When additional objects are read in, or as geometry is modified (e.g., points are added), memory is reallocated as needed. When objects are deleted, the memory is freed to make room for new objects.

Error checking is performed at all levels, starting at the GUI, when the user enters parameters. Any errors such as out-of-range data or invalid values are immediately reported so that the user can correct them.

The SmagglIce GUI is designed to provide “directed control,” or “guided use.” This means that the user will be prevented, through the desensitization of widgets (menus, buttons, sliders, etc.), from selecting conflicting functions or functions that are invalid in certain situations.

## **Role in Icing Effects Prediction**

SmagglIce deals with three main types of objects: elements, blocks, and grids. An element is either the entire or partial boundary geometry of a solid or a section of flow domain. For example, an element may be a clean or iced airfoil, or an isolated ice shape between upper and lower ice limits. Elements are typically processed in preparation for gridding to correct input errors, smooth the boundary, increase or decrease the number of points, and/or redistribute the existing points as discussed in the “Ice Shape Control Features,” section above. In figure 3, a smooth curve without any sharp corners was constructed using the control point formula that was presented in reference 3 and used in the task of reference 1. The shape of the smooth curve in bold is guided by the piecewise linear curve that is

formed by the control points denoted in diamonds. The number of control points determines the level of smoothing. All these processes can be applied to any given element using SmagglIce 1.0.

Once the iced airfoil boundary is prepared, the computational flow domain will be defined interactively through a dialogue box in which the user can specify upstream, downstream, upper, and lower boundaries in terms of multiples of the chord length. Domain decomposition will be performed by an automatic process with an option to use an interactive capability. Further blocking, merging blocks, or changing internal block boundary shapes using control points can be interactively performed, if desired. Perimeter discretization will be performed automatically, but the interactive process will allow users to re-discretize or redistribute points.

Quality grids require smoothness, orthogonality, and a proper resolution for viscous flow computation. With a clean airfoil, one can easily generate grids to meet these requirements. However, when ice is present, these requirements may conflict with one another. The difficulty of generating a quality grid with ice is illustrated using relatively simple ice shapes in figure 6. SmagglIce will utilize grid generation and quality control techniques that will provide quality viscous grids for iced airfoils. In particular, the control point form of algebraic grid generation in SmagglIce will provide explicit local grid control capability without any global effects as illustrated in figure 7. This shows that translation of a control point changes the grid only in a local region around the translated control point. When ice shapes are more challenging, with horns and cavities, the domain can be interactively divided into blocks as shown in figure 8. The flow solver WIND, described in reference 6, runs on such a blocked grid.

Grids may be modified either directly by stretching, smoothing, refining, and/or indirectly by moving points of the control net. Associated initial solution data can be read and displayed underneath the grid to guide the interactive improvement of grid quality. After grid changes are made, the solution can be re-interpolated to the modified grid.

File formats are defined for each of the entity types (elements, blocks, and grids), so that as modifications are made to them, they may be written to a file and later read back into SmagglIce or into another grid generation package.

SmagglIce is being developed for the overall process displayed in figure 9. The value of any technology component will constantly be weighed against its contribution to the overall process from iced geometry to aerodynamic solution. The SmagglIce code will be closely tied to WIND<sup>[6]</sup>, a flow solver that is supported

by the NPARC Alliance. SmagglIce will prepare and submit the WIND job, monitor its convergence, and evaluate the results. It is intended to become a software tool that will streamline the whole process shown in figure 2.

## **Status and Plans**

### **Phase 1**

Phase 1, which includes interactive ice shape probing and interactive ice shape control, is being released as SmagglIce version 1.0. The Alpha version was made available to aircraft icing engineers and researchers at NASA Glenn Research Center in June of 1999. The 1.0 Beta version was first introduced to the U.S. aircraft icing community in September of 1999 and has been available to them since November of 1999. Version 1.0 will be in production mode in February of 2000. The user-friendly interactive capabilities of SmagglIce will be useful to CFD analysis as well as in experimental model preparation and ice-shape comparison work.

### **Next Phases**

The remaining tasks of SmagglIce will be divided into two phases. In Phase 2, the code will be extended to perform domain definition and decomposition, perimeter discretization, field grid generation, and grid quality check, control, and refinement. These capabilities will be implemented in both the interactive and automatic modes in order to make the best attributes of each available to users when they work on difficult ice shapes. For instance, the grid quality check, control, and refinement can naturally be performed well interactively, while automatic domain decomposition for an iced multi-element airfoil can save a great deal of the user's time and effort. Innermost blocks for very complex ice shapes can still be constructed interactively using Bezier curves as block edges. In addition, the interactive probing features will be extended as desired by users. Version 2 will be released at the end of Phase 2.

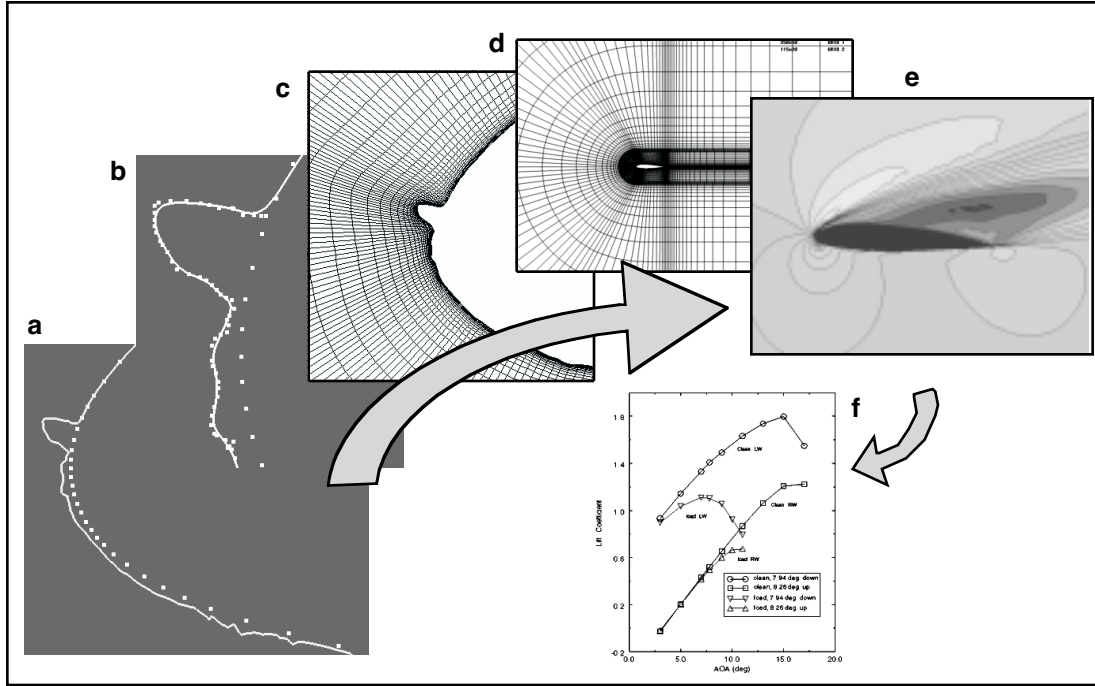
In Phase 3, the SmagglIce code will be closely tied to the WIND flow solver. Users can interactively prepare/check/submit WIND jobs, monitor their convergence, and choose to either terminate the iteration or return to the grid quality control process. The whole process from iced airfoil geometry to the aerodynamic performance prediction will be tested in this phase using SmagglIce and WIND for a number of iced airfoils. At the completion of this final phase, SmagglIce will truly make possible an interactive CFD process

for prediction of icing effects. Version 3 will be released at the end of Phase 3.

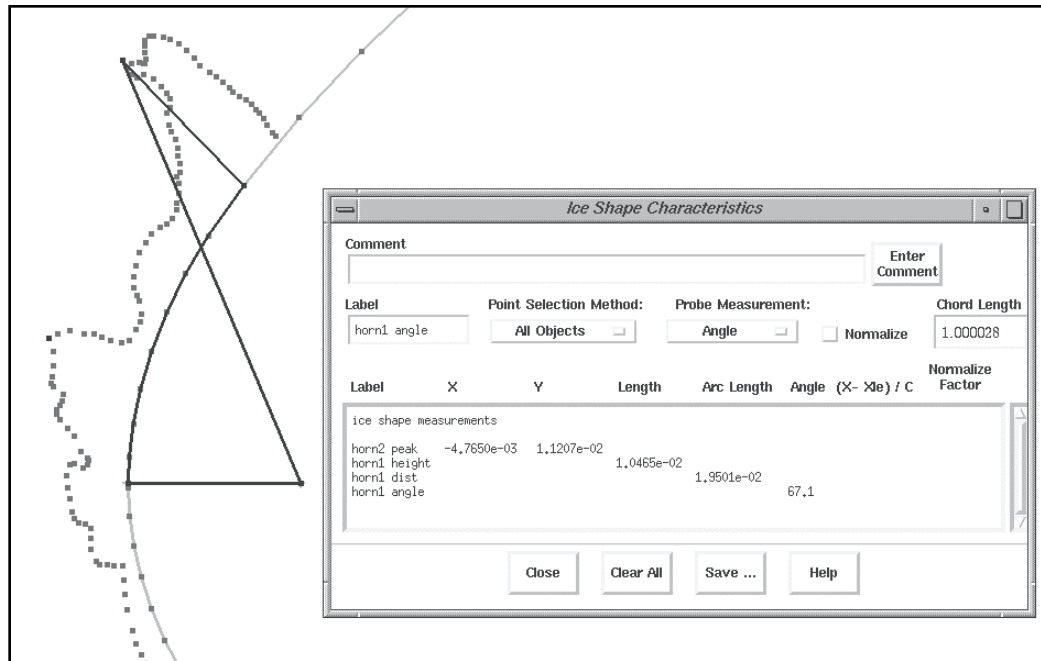
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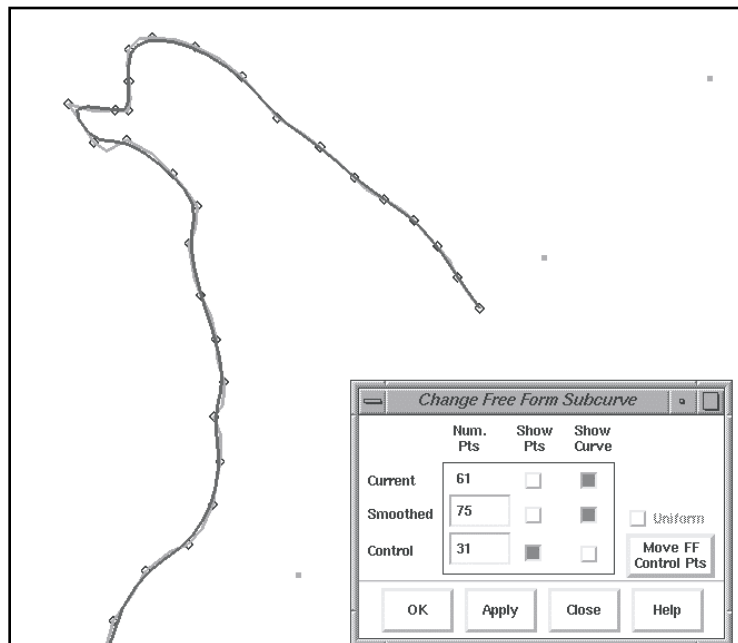
## Figures



**Figure 1.** Steps in determining iced airfoil performance degradation: (a) ice shape acquisition and characterization, (b) surface preparation, (c,d) definition and modification of flow domain and grid, (e) CFD flow analysis, (f) determination of airfoil performance (i.e., lift, drag).



**Figure 2.** Probing of ice shape characteristics: location, length, length, and angle. The measurements are made interactively by selecting points on the geometry and recorded in the table. Dark lines on the geometry indicate where measurements were made.



**Figure 3.** Curve discretization and smoothing using free form modification allows the user to change the number of control points and the number of points on the new smoothed curve. There is also an option to move control points around, thereby interactively changing the shape of the curve.

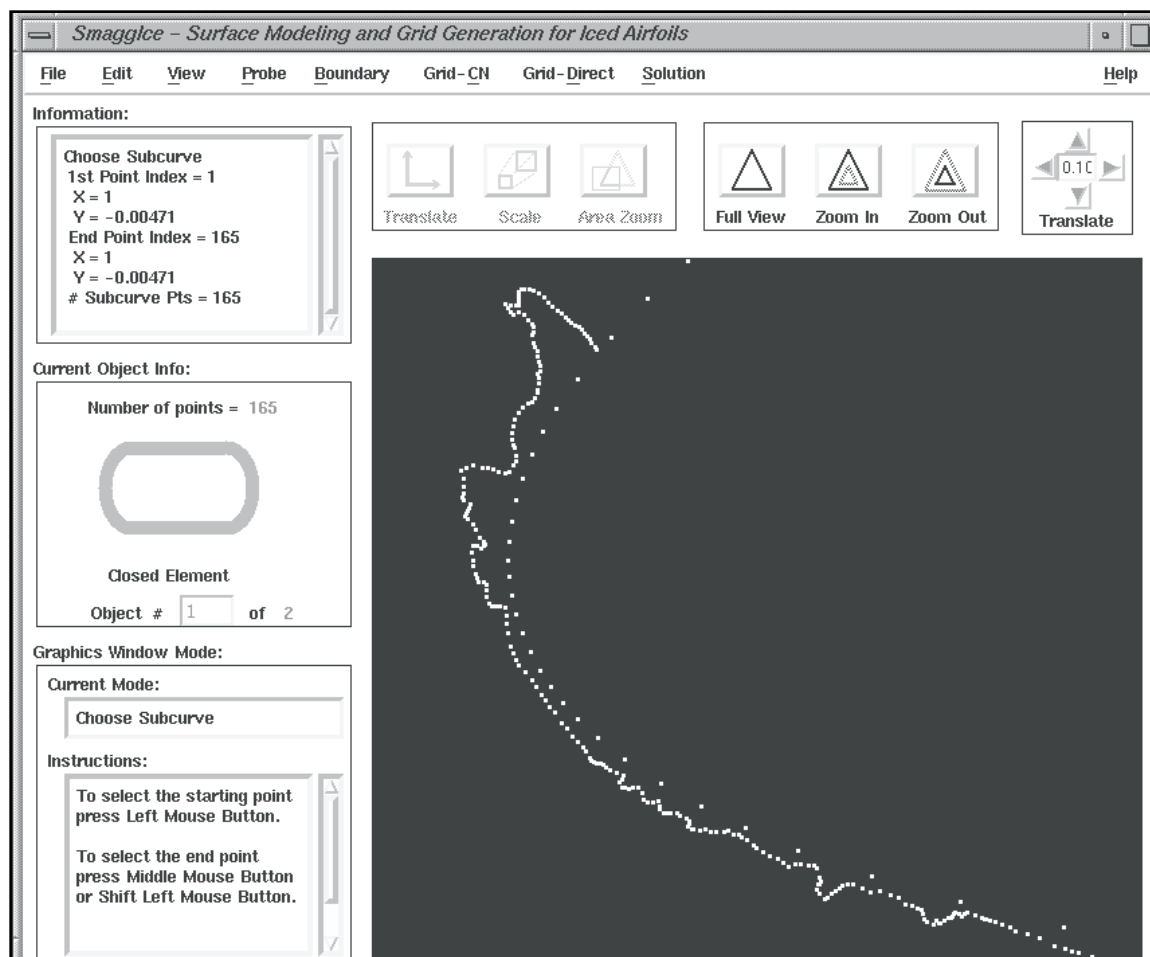


Figure 4. SmagglIce main screen.



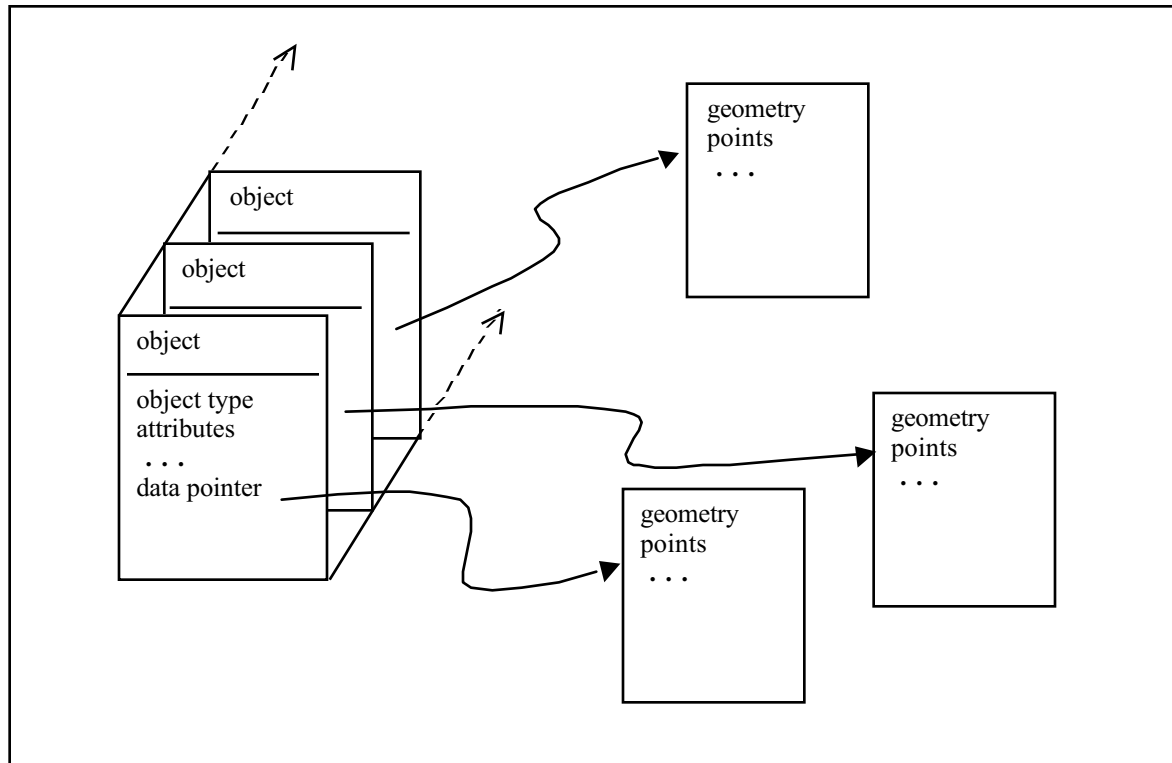
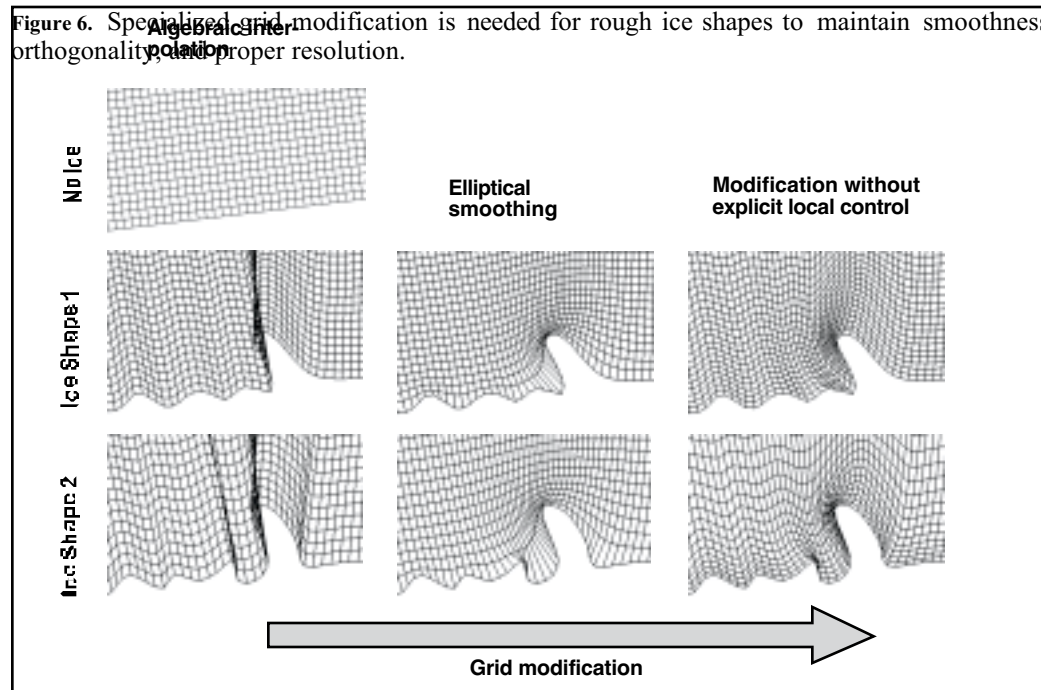


Figure 5. Data structures for multiple objects using dynamic memory.

Figure 6. Specialized grid modification is needed for rough ice shapes to maintain smoothness, orthogonality, and proper resolution.



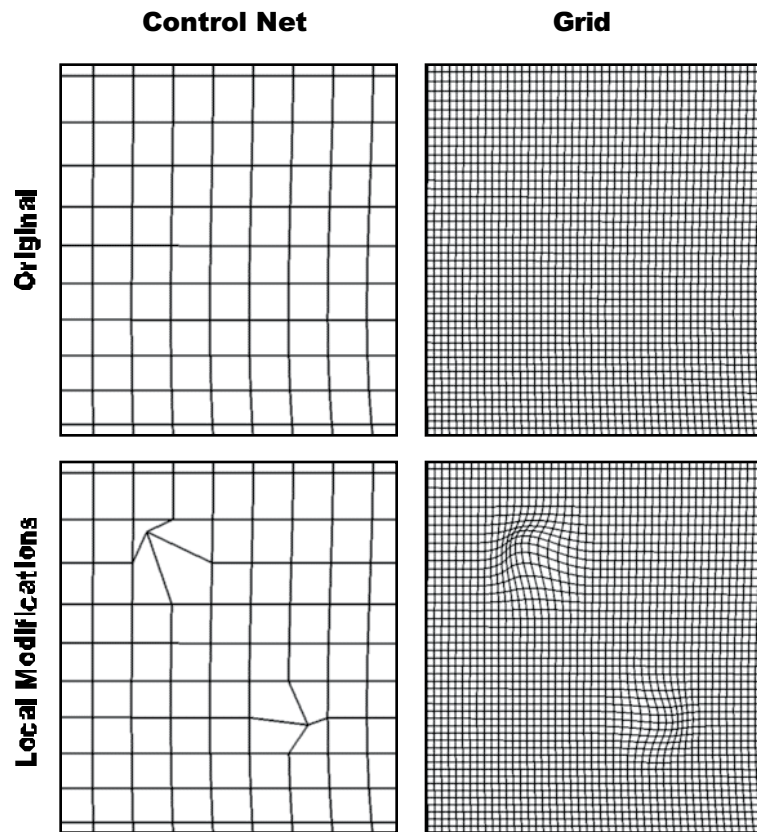


Figure 7. Explicit local control allows modification of parts of the grid (using control points) without affecting other parts of the grid.

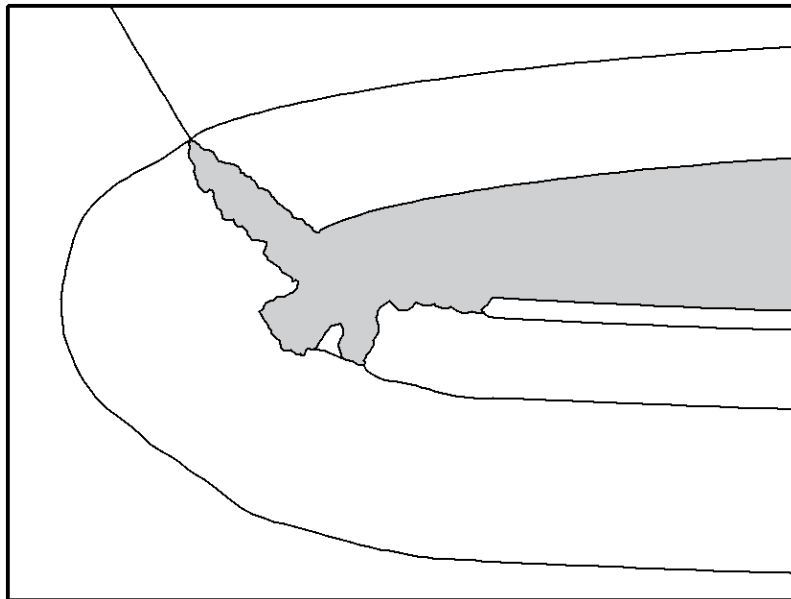


Figure 8. Block structure of flow domain around airfoil with complicated ice shapes.

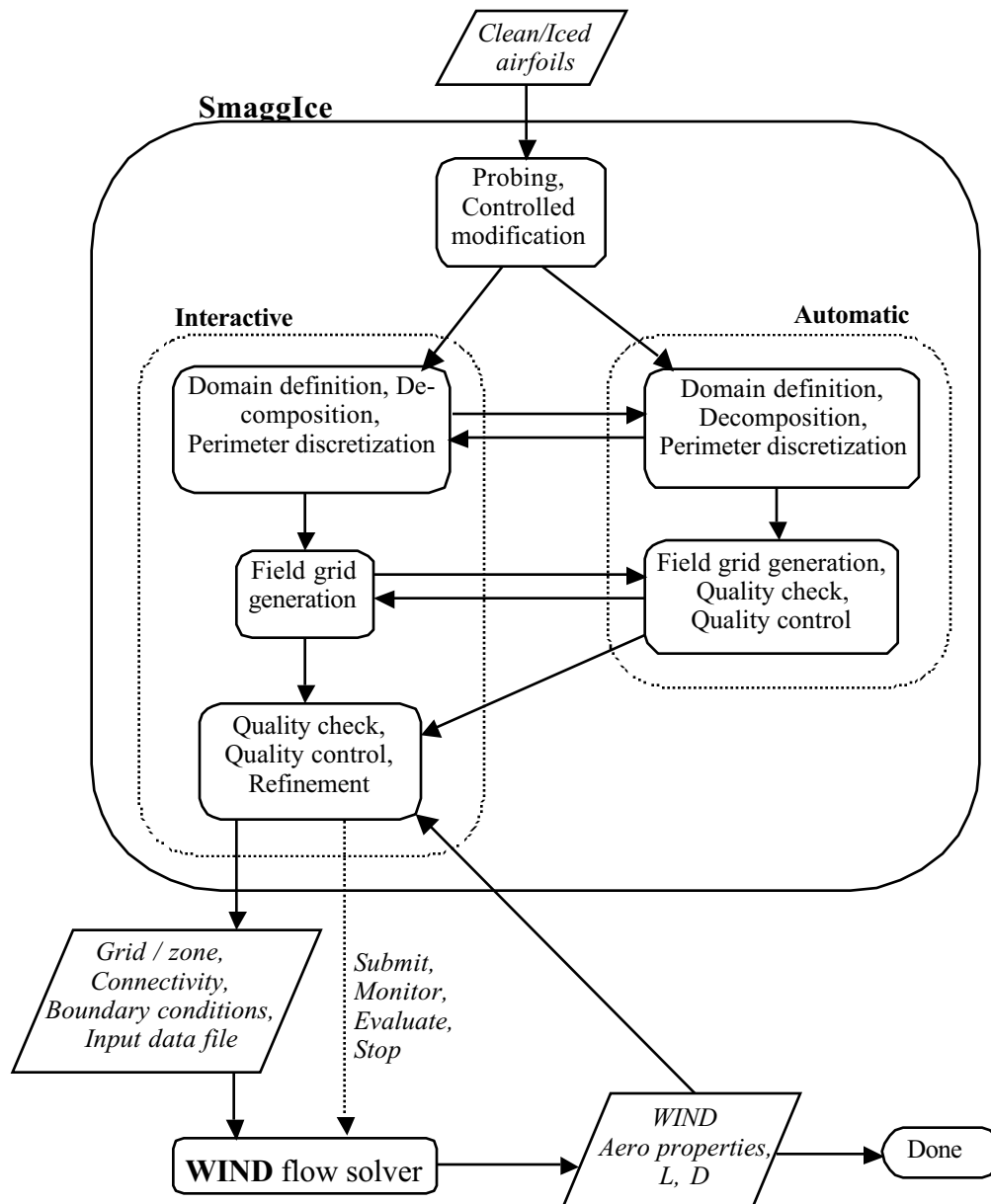


Figure 9. Overall process of interactive icing CFD using SmagglIce and WIND.